Comparison of heart rate and oxygen uptake relationship in water with that on land
by Lori Ann Klapperich

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
Montana State University

Abstract:
Water exercise is favored by many older adults due to the decreased risk of injury. However, there is very little information available on the physiological responses of upright water exercise. Knowing what heart rate response can be expected and if a relationship exists between heart rate and oxygen uptake aids in preparing an exercise prescription.

The major purposes of this study were to determine the relationship between submaximal oxygen uptake and heart rate in water during a step test and to assess the relationship between the land and water results in a elderly, female population.

Nine female volunteers, 55 years of age and older, were connected to a radio transmitter to relay heart rate and performed a step test. The subjects stepped up and down on a platform until heart rate monitoring indicated steady state had been reached. Expired air was collected in a meteorological balloon for one minute during steady state. The procedure was repeated on six steps of varying heights over two testing periods. The expired air was analyzed immediately upon completion of the test. The subjects performed the same stepping protocol immersed in water at 32-33°C to the level of the fifth intercostal space. The test was performed twice in each environment within a 4-5 week period.

In analyzing the results, it was found that the heart rates and oxygen uptakes were much higher on land for all intensities than in water. There were also larger increases in the heart rate and oxygen uptake as intensity increased on land compared to water. A bradycardia effect was indicated when going from land to water. The gradient of the HR/VO? curve varied withoeach subject and the relationship between HR and VC2 was not found to be linear.

The results may be due in part to insufficient stimulus, water buoyancy reducing the workload below the HR-VC2 critical level for a constant stroke volume, or differing relationships in an older female population.

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Lori Ann Klapperich

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Date October 31, 1988

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ABSTRACT

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The major purposes of this study were to determine the relationship between submaximal oxygen uptake and heart rate in water during a step test and to assess the relationship between the land and water results in a elderly, female population.

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In analyzing the results, it was found that the heart rates and oxygen uptakes were much higher on land for all intensities than in water. There were also larger increases in the heart rate and oxygen uptake as intensity increased on land compared to water. A bradycardia effect was indicated when going from land to water. The gradient of the HR/$\dot{V}O_2$ curve varied with each subject and the relationship between HR and $\dot{V}O_2$ was not found to be linear.

The results may be due in part to insufficient stimulus, water buoyancy reducing the workload below the HR-$\dot{V}O_2$ critical level for a constant stroke volume, or differing relationships in an older female population.

CHAPTER 1

INTRODUCTION

The search for maintaining youth started with Ponce de Leon in 1512. In the last decade and a half, the search for youthfulness has centered around physical exercise. Over half the population presently exercises in some form, compared to 24% in 1960 (Reed, 1981). The results of participating in exercise, moderating diet, controlling blood pressure, and lowering smoking rate appears to be positive, as reflected by health statistics (Edington, M.P., 1984; Reed, 1981). Comparing current health statistics with the 1967 figures, researchers have noted that the incidence of heart disease is down by 20%, stroke occurrences cut by 33%, and life expectancy has risen to 73 years (Reed, 1981).

Greater productivity and awareness, and even a slowing of the aging process, have been attributed to increased exercise (Reed, 1981). Further, researchers have reported that exercise may be the key to maintaining mental and physical functions, regardless of age (Bortz, 1982). In the review, Bortz also cited positive changes in cardio-vascular and pulmonary functions, blood components, body composition, enzyme action, and nervous system performance in a variety of different age groups; some specific changes observed were an increase in maximum oxygen consumption, lowered resting and exercising heart rate, strengthened heart muscle, lowered blood pressure, decreased triglycerides and cholesterol in the blood, increased muscle tissue, increased mobilization of fatty acids, and improved nerve conduction (Bortz, 1982).

Changes specifically examined in older persons in relation to exercise include positive health changes (Smith & Serfass, 1981). However, there are some inherent problems with exercise for elderly people, as well as other health compromised groups.

There are a variety of health problems that older adults face when exercising. A major problem is the effect of gravity on the body. The force of gravity on the muscles, joints and bones supporting the body makes it very difficult for some older adults to do the kinds of exercises that promote muscular development and strength and increase aerobic capacity. There are other problems that older adults face, bones become brittle and are more apt to break and compress (Review by Bortz, 1982; Brooks and Fahey, 1984; Smith and Serfass, 1981); muscles become flaccid, while tendons and ligaments lose flexibility and strength, resulting in increased tendency for strains and pulls (Brooks and Fahey, 1984). The occurrence of injury and the fear of falling are also common in elderly populations (Claremont, Reddan, and Smith, 1981).

The support provided by the water helps diminish some of the fear of falling. In addition, exercising in water allows people to exercise in a medium where physical activity is performed with the detrimental effects of gravity being compensated by the buoyancy of water. However, there is very little information available on the physiological responses of upright water exercise. Research has been conducted regarding the physiological responses to swimming (DiPrampero, Pendergast, Wilson & Rennie, 1974; Holmer & Bergh, 1984; McArdle, Claser, & Magel, 1973); Pendergast, DiPrampero, Craig, Wilson, & Rennie, 1977), to diving (Dwyer, 1977 & 1983; Goff, Brubach, Specht, and Smith, 1956; Hong, Cerretelli, Cruz, and Rahn, 1969; Hood, Murray, Urschel, Bowers, and Goldman, 1968) and to cycling exercises (Costill, 1971; Craig and Dvorak, 1968 & 1969; McArdle, Magel, Lesmes, and Pechar, 1976) performed in the water. However, it is not known whether the physiological responses to upright exercise performed in water are the same or similar to the type of responses elicited by land exercise. The knowledge of the heart rate response is especially important because of its use in exercise prescription. Knowing the relationship that exists between heart rate and oxygen uptake also aids in determining intensity of exercise and exercise prescription.

Statement of the Problem

The major purposes of this study were to determine the relationship between submaximal oxygen uptake and heart rate in water during a step test and to assess the relationship between the step tests in water and on land, in an elderly population. The results were examined to see if any difference existed between the heart rate/$\dot{V}O_2$ relationship or the gradient of the heart rate/$\dot{V}O_2$ curve in water as compared to that observed on land, for the same individual.

Hypotheses

1. The heart rate/$\dot{V}O_2$ relationship in an aqueous environment is linear for submaximal work.

2. The gradient of this linear heart rate/$\dot{V}O_2$ relationship in an aqueous environment is the same as that observed on land, for the same subject, for submaximal work.

Delimitations

1. Subjects tested were women volunteers, 55 years of age or older.

2. Subjects were required to get personal physicians' approval prior to participation in the study.

3. All were participants in the Young at Heart exercise program. (Young at Heart is an exercise program conducted for adults 55 years of age and older.)

4. Water temperature was fixed at 32-33 degrees Celsius.

5. Effects of differing environmental temperatures were not measured in this study.

Limitations

1. The subject group was derived from a diverse age sample, ranging from 55-77 years of age.

2. The results of testing the participants of the study could vary from the results of testing members of the general public, in the same age group, due to their involvement in an exercise program at the time of the study.

Definition of Terms

Aerobic Exercise - Exercise during which the energy needed is supplied by inspired oxygen.

Age-Predicted Max Heart Rate - Mean highest heart rate attained during effort by individuals of various ages.

Bradycardia - Slowing of heart rate.

Cardiac Output (Q) - Volume of blood pumped from a ventricle of the heart per unit of time; product of heart rate and stroke volume.

Douglas Bag - A rubber-lined canvas bag used for collection of expired gas.

Karvonen's Formula - 220 - age = Maximum Heart Rate - Resting Heart Rate = Heart Rate Reserve x Exercise Intensity + Resting Heart Rate = Target Heart Rate.

Oxygen Uptake - Oxygen used by the mitochondria in all of the body cells.

Pulse - Periodic expansion of the artery resulting from the systole of the heart.

R-Squared Test - Test of nonlinearity.

Spirometer - An instrument used to measure lung volumes and dynamic lung function.

Stroke Volume - The amount of blood pumped out of the ventricles with each contraction.

<u>Steady State Exercise</u> - A work situation where oxygen uptake equals the oxygen requirement of the tissues. Heart rate, cardiac output, and pulmonary ventilation have attained fairly constant levels.

<u>STPD</u> - Standard temperature, pressure, dry.

<u>Submaximal Exercise</u> - Exercise at less than maximal intensity and/or duration.

<u>Tissot Tank (spirometer)</u> - A very large water-sealed spirometer designed for accumulating expired gas over a long period of time; the counterbalancing of the bell is compensated for the bell's change in buoyancy as it emerges from the water, keeping the contained gas precisely at ambient atmospheric pressure.

$\mathring{V}O_2$ - Oxygen consumption per unit of time.

$\mathring{V}CO_2$ - The rate at which CO_2 is produced per minute.

CHAPTER 2

REVIEW OF LITERATURE

Participants in exercise on land are at risk for injuries. Therefore, exercise in water has been used for rehabilitation, therapy, and general conditioning. Exercising in water appears to minimize the fear of falling, muscle strains, and other injuries related to exercise on land (Claremont, Reddan, and Smith, 1981). The buoyancy effect allows easy movement of body parts amd compensates for the pull of gravity. This effect is very important for the populations using this form of exercise.

Water immersion, however, results in changes in the circulatory and pulmonary systems; exercise may amplify these changes. Research on the effects of water immersion has centered around its effects on hemodynamic changes, metabolic responses, exercise responses, thermal regulation, cardiovascular and pulmonary function, and bradycardia. Changes in heart rate, cardiac output, oxygen uptake, tidal volume and vital capacity are a few of the variables measured in the studies found in the literature. The results from previous studies have not been consistent, but the inconsistencies might be associated with the differences in the individuals' responses to water immersion (Farhi and

Linnarsson, 1977), the methodology used in measuring the changes in body components (Arborelius, Balldin, Lilja and Lundgren, 1972), or the effects of water temperature (Craig and Dvorak, 1966).

Circulatory System Readjustments

Water immersion has been cited as a probable initiator of certain circulatory system readjustments including changes in heart rate, oxygen uptake, stroke volume, and cardiac output. The changes have not been consistent in many of the studies.

Heart Rate

Farhi and Linnarsson (1977), in their study on the cardiopulmonary readjustments during graded immersion in air and water at 28° C and 35° C, respectively, found a decrease in heart rate between the dry subjects and the subjects immersed up to their xiphoid in water. The researchers measured cardiopulmonary changes in six males (25-34 years) under four conditions: in air; and in water at the hips, xiphoid and chin. A decreasing heart rate trend was noticed but reversed as the depth of the water increased. However, the heart rate in water remained below the value in air. No significant changes in steady state heart rates were found by Arborelius et al. (1972), when they studied ten male subjects (20-31 years) in air at 28° C, and immersed, head out, in water at 35° C. Craig and Dvorak (1966) noticed an increase in heart rate in ten male subjects (20-32 years) immersed in warm water during their study on thermal regulation, but the value still remained less than the control value, on dry land. Hood, Murray, Urschel, Bowers, and Goldman (1968), saw a continuous decline during immersion. Hood et al. (1968), studied the effects of water immersion on circulation of five human male subjects (20-29 years) during two eight-hour periods of bed rest and total immersion. Arrhythmias were recorded in individuals when first immersed in water. These irregularities in heart beat were thought to be a result of hyperventilation (Farhi and Linnarsson, 1977; Strauss, 1970).

Theories regarding the causes of these changes are varied. Song, Lee, Chung, and Hong (1969), in their study on the mechanism of apneic bradycardia in five healthy young males, posed a multiple-factor theory to explain the drop in heart rate, observed by a large number of the researchers. The explanation is comprised of two separate mechanisms which work together to lower heart rate, a mechanical mechanism and a neural mechanism.

The mechanical theory emphasizes the role of venous return, and arterial blood pressure in regulating heart rate. Venous return and arterial blood pressure are greatly influenced by the amount of transmural pressure across the thorax. Farhi and Linnarsson (1977) and Paulev (1968) in work on cardiac rhythm during breath-holding and water immersion in thirty male subjects (21-32 years), and Strauss (1970) in his review of literature on the physiological aspects of mammalian breath-hold diving, viewed the mechanical mechanism as a reason itself, for lowering of heart rate.

In the neural reflex theory, the lowering of heart rate is a reflex action postulated to result from a distention of the stretch receptors in the atrial walls. The reflex theory also is dependent upon increased blood flow in the thorax caused by the hydrostatic effect of water immersion.

Earlier research by Keatinge and Evans (1961), testing twelve men, suggested HR response was part of skin temperature adjustment. After measuring respiratory and cardiovascular responses to immersion for twenty minute periods, in cold and warm water in twelve men, the investigators suggested water temperature as a prime cause of bradycardia during immersion. Claremont, Reddan and Smith, as edited by Nagle and Montoye (1981), agreed that during water immersion, the lowering of the heart rate was a reflex response caused by the change in skin temperature, when dealing with an elderly population. Paulev (1968) and Craig and Dvorak (1966) stated temperature could be a cause, but vasodilation and vasoconstriction were the instigators rather than a reflex response. The implication was that the lowered heart rate is a humoral response rather than a reflex response.

Oxygen Uptake

Oxygen uptake has been shown to increase when subjects were immersed in nine different water temperatures (24 -37° C) for one hour (Craig and Dvorak, 1966). Shivering was one reason thought to cause an increase in oxygen uptake (Craig and Dvorak, 1966); oxygen uptake was seen as a function of water temperature. In Crowden's (1935) study, oxygen uptake decreased in the one individual studied while doing exercise immersed in water up to the neck. No change was seen in the oxygen uptake value in studies done by Cohen, Bell, Saltzman, and Kylstra (1971), who measured alveolar-arterial oxygen pressure differences in nine subjects immersed in water up to the neck. Krasney, Pendergast, Powell, McDonald, and Plewes (1982) also noticed that oxygen uptake remained the same when testing the circulatory responses to head-out immersion in eight anesthetized dogs. The dogs were studied in a position that resembled humans and many of the adjustments that occurred with the dogs can be extrapolated to the human response, according to Krasney et al. (1982).

Cardiac Output

Cardiac output tended to increase during water immersion (Arborelius et al. 1972; Begin et al. 1976; Farhi and

Linnarsson, 1977; Krasney et al. 1982). Arborelius et al. (1972) reported that the increase in cardiac output they noticed in their testing was a result of improved diastolic filling which increased stroke volume in the ten subjects studied. Farhi and Linnarsson (1977) attributed the increased cardiac output to temperature effects.

Stroke Volume

Water immersion also caused an increase in stroke volume (Arborelius et al. 1972; Farhi and Linnarsson, 1977; Hood et al. 1968; Krasney et al. 1982). Increased stroke volume was a direct result of improved diastolic filling according to Arborelius et al. (1972), while Krasney et al. (1982), thought that increased stroke volume was related to the Frank-Starling Mechanism as heart volume increased. The Frank-Starling Mechanism refers to the increased contraction of the heart muscle caused by stretching of the muscle fibers upon increased filling of the cardiac chambers.

Pulmonary System Readjustments

Tidal volume, vital capacity, functional residual capacity, pulmonary tissue volume, arterial-alveolar CO_2 difference, mixed venous O_2 and CO_2 pressures, as well as expiratory reserve volume are routine measures of pulmonary system functioning. They are all affected by immersion in water. The responses are thought to be caused by hydrostatic pressure acting on the body as a result of immersion (Cohen et al. 1971; Farhi and Linnarsson 1977; Krasney et al 1982). In earlier work, Hong, Ceretelli, Cruz, and Rahn (1969) came to this conclusion also. In the study performed by Hong et al. (1969), four male subjects (31-52 years) were immersed in water at temperatures ranging from 25-30° C and the mechanics of respiration were examined. Changes in lung volumes, total intrapulmonary pressure, intergastric pressure and the total work of breathing during immersion were recorded during steady state and non-steady state conditions.

Tidal volume remained unchanged during water immersion while vital capacity and expiratory reserve volume decreased (Hong et al. 1969). Hamilton and Mayo (1944) concluded earlier, after studying 20 male students, that the decrease in vital capacity was due to the increase in flow of blood to the lungs and a decrease in space available for air. The decrease in vital capacity and expiratory reserve volume, according to Hong et al. (1969), and Risch et al. (1978), was attributed to a raising of the diaphragm and an increased flow of blood into the thoracic area. Increased hydrostatic pressure caused the redistribution of blood.

Keatinge and Evans (1961) cited an increase in pulmonary ventilation while the male subject studied was immersed in water, whereas Cohen et al. (1971), in examining the alveolar-arterial oxygen pressure differences in nine male subjects (20-30 years) during immersion, noted a non-significant decrease in pulmonary ventilation.

The subjects' pulmonary tissue volume increased during immersion, having equal and opposite responses to functional residual capacity (Begin et al. 1976; Farhi and Linnarsson, 1977). Cohen et al. (1972), Farhi and Linnarsson (1977) and Hong, Ceretelli, Cruz, and Rahn (1969) all noted a decrease in functional residual capacity. Blood pooling (Hong et al. 1969) and elevation of the diaphragm (Cohen et al. 1972) were the major causes noted for this decrease. Cohen et al. (1972) did not find a significant change in any of the subjects' arterial-alveolar CO_2 during immersion, while Farhi and Linnarsson (1977), and Keatinge and Evans (1961), found a decrease in the value of arterial-alveolar CO_2 in their subjects. The rising diaphragm caused a decrease in the lung volume of the subjects studied; trapped air in the lungs also appeared to cause a similar adjustment.

Mixed venous O_2 and CO_2 pressures served as indicators of tissue gas tensions. Mixed venous O_2 increased along with the increase in cardiac output while mixed venous CO_2 remained unchanged. The mixed venous CO_2 value remained more consistent because it can be easily monitored by minor changes in alveolar ventilation (Farhi and Linnarsson, 1977).

Hydrostatic pressure appears to contribute to circulatory and pulmonary readjustments. Farhi and Linnarsson (1977) theorized that there is a direct relationship between hydrostatic pressure and hemodynamic responses on circulatory and pulmonary readjustments. As the water level reaches the pelvis, the blood is displaced from the leg veins and redistributed throughout the circulatory system, causing a very minor increase in thoracic blood volume. Functional residual capacity is not affected at this point. The right atrium increases only slightly and there is a small rise in cardiac output. Heart rate is lowered because of the increased systemic arterial pressure. When the water reaches the abdomen, major changes take place. The compression of the abdomen by the water causes a displacement of blood into the thorax and the diaphragm rises. This action causes an increase in thoracic blood volume as well as trapped air in the lungs. The results of this increased hydrostatic pressure are increased cardiac output, increased heart rate, increased stroke volume, and increased pulmonary capillary volume. The diaphragm rising decreased lung volume, causing a decrease in functional residual capacity. When the water reaches chin level, many of the adjustments start to level off. Cardiac output increase is limited because venous return cannot be further improved. Pulmonary blood volume no longer increases and atrial stretch receptors come into play because of the increased pressure in the atrium. This action causes an increase in heart rate, a moderate increase in stroke volume, and further decrease in functional residual capacity. Various authors, including Sheldahl et al. (1984), in their investigation of the effect of different levels of central blood volume on cardiac performance during exercise in twelve young men (22-34 years), and Krasney et al. (1982), in their research on the anesthetized dog, support this theory.

Cohen et al. (1971) reported that blood volume influenced circulatory and pulmonary readjustments, while Craig and Ware (1967) and Hong et al. (1969) stated that increased pressure was prominent in the readjustments. Arborelius et al. (1972) warned that this increased blood flow and pressure could cause a strain on the heart.

Pleural pressure, intra-arterial blood pressure, mean pulmonary arterial pressure, transmural pressure gradient of pulmonary artery, and mean atrial pressure were other pressures found to have increased, while systemic vascular resistance decreased (Arborelius et al. 1972). Hood et al. (1968), noticed a decline in arterial blood pressure when the five subjects they studied were immersed. A decrease in peripheral vascular resistance of the participants was also recorded. The venous blood pressure fell in response to the negativity of the airway pressure with an increase in ambient pressures as depth of immersion increased. No significant change in blood volume was noticed. There was, however, a rise in the hemoglobin and hematocrit values. This factor, the researchers stated, could be the result of decreased plasma volume caused by negative pressure breathing.

Exercise

The preceding description of the processes involved during water immersion are important when trying to compare exercise in the water to a corresponding workout on land. Readjustments by the body systems are unavoidable during immersion. Exercise may or may not amplify these adjustments.

Claremont, Reddan, and Smith, as edited by Nagle and Montoye (1981), stated that water support exercises would be a good way to increase the participation of the elderly in exercise. The fear of falling would be reduced, but still a sufficient stimulus for training at lower cardiac costs would be provided. Claremont et al. (1981), reported that the oxygen uptake and heart rates increased with water depth in the five males (64-77 years) and six females (54-62 years) tested, although heart rates were lower in all individuals in water than on land. The researchers warned against extrapolating a training heart rate in humans from land to water because of the tendency for a lower heart rate at the same metabolic demands as land exercise.

Kirby, Sacamano, Balch, and Kriellaars (1984) studied thirteen able-bodied subjects, five men and eight women (21-27 years), walking and running in the water. The researchers found that enough energy could be expended during various forms of water therapy to elicit an aerobic training effect and that the exercise was strenuous enough to be a risk for anyone with coronary artery disease.

Sheldahl et al. (1986), also found that the energy expended during water exercise was sufficient to elicit an aerobic training effect. The researchers were concerned that the cephalic shift in blood volume would alter the training effect. The study included twenty-two middle-aged healthy men. Nine trained on a cycle ergometer in the water, nine trained on a cycle ergometer on land, and four served as controls. No significant differences were noticed in the variables in water or on land. In both cases the submaximal heart rates were lower, stroke volume higher, cardiac output unchanged, systolic and diastolic blood pressure lower, after training. Sheldahl et al. (1986) noticed no change in resting values.

Costill, Cahill and Eddy (1967) described the results from eight young men (18-29 years) exercising for twenty minutes in different water temperatures and found no significant differences existed in energy requirements for different water temperatures. However, cold water did allow a faster recovery after exercise.

In 1971 Costill performed another study, comparing the heart rate response and work efficiency of exercise performed by ten physically active men (21-36 years) horizontally on land and in the water. The findings were compared to the control subject, who remained sitting on land. The researcher found that the oxygen uptake during submaximal work loads in water was greater than on land. Water exercise required a higher energy input. The heart rates in this study were higher in the water compared to land.

Craig and Dvorak (1969) noticed a linear relationship between oxygen uptake and added workload in water. The subjects' oxygen consumption, for the two male subjects studied, were higher compared to land values, but heart rates were lower. A relationship with heart rate and water temperature was theorized. In the earlier research of Goff, Brubach, Specht and Smith (1956), they reported a relationship between water temperature and heart rate when the oxygen uptake of four male subjects (30-46 years) was measured at rest and during mild exercise on land and in water at temperatures which ranged from 29.5-36.5°C, over twenty-minute periods. The researchers stated that oxygen consumption and heart rate appeared to vary more with water temperature than immersion per se.

Evans, Cureton, and Purvis (1978), found that the heart rate in water was nearly the same as that on land. These results are in conflict with much of the previous research. Evans et al. (1978) attribute this difference to the warm water temperature during water exercise (30-31° C). In the study, six physically active males (21-42), walked or jogged in waist deep water and on the treadmill at specified speeds. Oxygen uptake, heart rate, and the respiratory exchange ratio increased nearly linearly with increased speed in both water and on land. Increase in ventilation was slightly curvilinear as the speed increased. In both the water and treadmill exercise, the relationship of heart rate to oxygen uptake was linear. There was no significant difference in the heart rate - oxygen uptake relationship during water and treadmill walking and jogging. The researchers concluded that the energy required to walk or run at any given speed in waist deep water was much greater than in air on the treadmill.

Rennie, DiPrampero, and Cerretelli (1977), tested the effects of head-out immersion in water (22-36° C) on mixed venous gas tensions, cardiac output, heart rate, stroke volume, and limb blood flow. Three subjects were studied in both a resting and exercising state. The researchers reported no statistically significant difference between mixed venous gas tensions in air or water during exercise. Also, the relationship between cardiac output and oxygen uptake remained the same whether in water or on land. The authors also reported lowered heart rates and attributed them to cooler water and vasoconstriction. The authors concluded that stroke volume would be increased since cardiac output remained the same, as heart rate lowered. A similar finding was described by Avellini, Shapiro, and Pandolf (1983), in an earlier paper, after testing fifteen unconditioned men (18-28 years) in water and on land during training on a cycle ergometer. Three groups were formed - five trained on land, five trained immersed to the neck in water of 32° C, and five trained immersed to the neck in water of 20° C. The groups exercised five times a week for an hour over a one-month period. Heart rates averaged ten beats per minute less in the water than on land.

In other studies, subjects who exercised in water had a higher absorption of oxygen per pulse beat than that observed on land. The investigators concluded that this was an indication of a higher level of efficiency throughout the body (Hill, 1950; Sheldahl et al. 1984). Hill (1950) also noticed that the increased oxygen consumption in a male subject, 77, was sustained over a period of hours following exercise.

Distribution of body fat also played a large role in heart rate, ventilation and other circulatory and pulmonary adjustments during exercise in the water. The subcutaneous fat tissue enhanced the effects of vasomotor adjustments, enabling more obese people to retain metabolic heat longer.

In a number of studies where subjects performed exercise at various temperatures, the more obese were not able to continue to work in the higher temperatures, lost more weight and had a higher heart rate and oxygen uptake, indicating a greater work output (Craig and Dvorak, 1969; McArdle, Magel, Spina, Gergley, and Toner, 1984).

Water temperature, body fat, exercise intensity and an individual's ability to maintain high levels of exercise are important factors in determining the relative response of the body to exercise in the water (McArdle et al. 1984). More research is needed on the effects of water immersion on exercise. This research will allow contradictions that have been noted in the literature to be either validated or expunged. Much of the research was done fifteen to twenty years ago. With modern methods of measurement, uniform results could be obtained and, thus, standard norms developed for water exercise.

CHAPTER 3

METHODOLOGY

The study was designed to measure heart rate and oxygen uptake in a land and water environment during resting and exercising conditions, using a multiple-height step test. All experiments using the land protocol were conducted at the Movement Science Laboratory and all experiments using the water protocol were conducted at the Romney Gymnasium Pool at Montana State University.

Subjects

Subjects were female volunteers, 55 years of age and older, and participants of the Young at Heart Exercise Program. To be included in the study, the participants were required to have a doctor's written approval, and to complete an informed consent form. Sixteen women volunteered, nine completed testing. Two persons dropped out due to illness, and the other five decided not to participate. All subjects went through both the water immersion protocol and the land protocol.

Apparatus

Body weight was measured using a standard clinical scale. Blood pressure was measured by manometry, using a blood pressure cuff and stethoscope. Maximum heart rate was determined using Karvonen's formula (220 - Age = Maximum HR - Resting HR = HR Reserve x .75 + Resting HR). During the course of the study, heart rate was monitored by radio telemetry; two electrodes were placed on locations V-1 (fourth intercostal space to the right of the sternum) and V-4 (left midclavicular line in the fifth intercostal space) and attached to a Narco-Bio System radio transmitter. Heart rate was transmitted via FM radio. Heart rates were determined directly from the time interval for ten complete beats. A metronome was used to maintain the speed of stepping, twenty two complete step-ups per minute. Six platforms of heights ranging from two to nine and one-half inches with one and one-half inch intervals were used for the testing procedure. Barbell weights were used to keep the platforms submerged in water. Oxygen uptake was determined using open circuit spirometry with expired air collected in meteorological balloons after passing through a mouthpiece, PVC (poly vinyl chloride) piping, and a one-way valve. The tubing was supported on a wooded stand in front of the person stepping. Expired air volumes were determined by drawing the air from the balloons into a tissot tank.

The oxygen and carbon dioxide concentrations were measured using a Beckman E2 and a Beckman LB-2 O_2 and CO_2 analyzer respectively.

Procedure

Land

Standing comfortably on land and connected to the radio transmitter, the subjects breathed through the breathing device so their air would be in the system, decreasing the possibility that environmental air would remain in the tubing and be analyzed along with expired air. The collected air was removed. Three platforms were used at each testing period, the three lower heights were used for the first session and the three higher platforms were used for the second session. The subjects started on the lowest platform and stepped until a steady state heart rate was reached. The heart rate was monitored every thirty seconds and then recorded when steady state was reached. Expired air was collected in a meteorological balloon for one minute during steady state. The subjects repeated the same procedure for the other two heights. The expired air was analyzed immediately upon completion of the test.

Water

The subjects performed the same stepping protocol as on land, immersed in water at 32-33°C to the level of the fifth intercostal space. The radio transmitter was protected from water in a small plastic container connected to the swimming suit. The wooden stand containing the collection device was transported to poolside.

The subjects performed each test twice within a 4-5 week period. Any contraindications to exercise, as noted by the American College of Sports Medicine, was reason to discontinue testing for any particular subject. For ease of testing and transporting equipment the land tests were conducted first, followed by the water test. There was one exception to the procedure - one woman started the testing late and only finished two of the land tests before the apparatus was moved to the pool. She finished her land test after completing the water test.

Gas Analysis

Expired gases were analyzed by pumping the air from the meteorological balloons through the E2 oxygen analyzer and the LB-2 medical gas analyzer. Air volume was measured by collecting the expired air in the tissot tank, as well as adding the amount of the sample analyzed. Oxygen and carbon dioxide concentrations in the expired air were obtained and used together with volume measurements to calculate oxygen uptake.

Data Analysis

Heart rates and oxygen uptake results were plotted against each other on a scattergram for land and water for each subject. Using the statistical package MINITAB, a regression equation for a line of best fit was generated. The lines of best fit for land and water were compared for gradient, position to one another, and linearity, for each individual. The R-squared function was used to calculate the degree of linearity (Joiner, Ryan and Ryan, 1985). Seventy percent and above is considered a high degree of linearity while fifty percent and below is considered a low degree of linearity (Ball, F. Statistical Consultant, personal communication, March 14, 1988). Heart rates were analyzed to determine bradycardia effect.

CHAPTER 4

RESULTS

Heart Rate

The heart rates in water were much lower for all intensities of exercise than the heart rates on land. The graphs illustrate that there were larger increases in the heart rate as intensity increased on land compared to water. Also, as noted by Table 1, the heart rate decreased in almost all cases when going from land to water, indicating a bradycardia effect.

Oxygen Uptake

There was a greater oxygen uptake on land than in water for all subjects for the same step height. A greater increase in oxygen uptake as intensity increased on land was also noted.

Gradient

The gradient of the HR/$\dot{V}O_2$ curve varied with each subject. In some cases, the land function had a steeper rise, for others the water function rose at a steeper level. Examples of a declining function also existed as seen in the water functions in Figure 4, Figure 7, Figure 9, Figure 11, Figure 13, Figure 15 and Figure 17. Trial I and II of Subject III (Figures 5 & 6) have approximately the same gradient.

R-Squared Testing

The measure of linearity was figured with the R-squared function. As can be seen from the graphs, the R-squared percentages of the land HR/$\dot{V}O_2$ were high, while those of many of the water HR/$\dot{V}O_2$ curves were very low. The land R-squares were above seventy percent except for Subject II, Trial I (Figure 3); Subject VII, Trial I (Figure 13); Subject IX, Trials I and II (Figures 17 & 18). This indicated a high degree of linearity. Only six of eighteen of the water R-squares were above fifty percent, indicating a very low degree of linearity for the water values. The one trial, Subject II, Trial II (Figure 4), which also had very similar gradients for the land and water function, indicates a high degree of linearity for both functions. Subject II, Trial I (Figure 3) and Subject VII, Trial II (Figure 14) were the only two trials where the water function had a higher degree of linearity. No degree of linearity was observed for the water function of Subject IX, Trial II (Figure 18).

Table 1. Heart Rate Response to Immersion in Water

Subject	I	II	III	IV	V	VI	VII	VIII	IX
Trial I									
HR-resting on land	76	89	67	80	100	65	114	80	100
HR-resting in water	68	73	63	69	71	62	90	71	96
% Drop	11	18	6	14	21	5	21	11	4
Trial II									
HR-resting on land	86	75	70	91	86	75	115	77	102
HR-resting in water	73	69	64	83	79	69	91	67	95
% Drop	15	8	9	9	8	8	21	13	7

Note: Mean HR Trial I - resting on land 85.67

Mean HR Trial I - resting in water 73.67

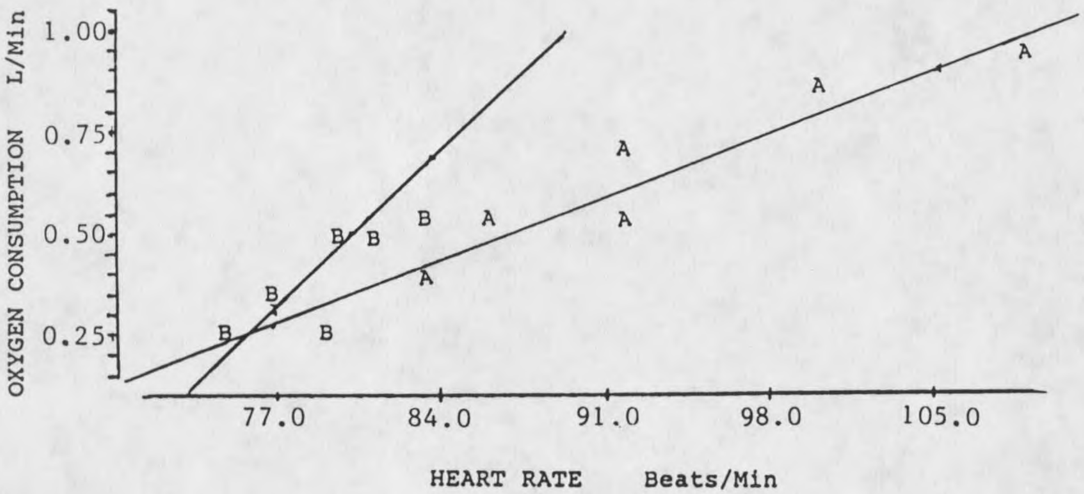
Mean % Drop 14%

Mean HR Trial II - resting on land 86.33

Mean HR Trial II - resting in water 76.67

Mean % Drop 11%

Figure 1
Relationship for $\dot{V}O_2$ and HR in Land
and Aqueous Environment
Subject I, Trial I



A=LAND$\dot{V}O_2$1 vs. LANDHR1 B=WAT$\dot{V}O_2$1 vs. WATHR1

Regression Equation: A
LANDHR1 = 65.9 + 41.6 LAND$\dot{V}O_2$1

Predictor	Coef	SD	t-ratio
Constant	65.909	3.984	16.54
LAND$\dot{V}O_2$1	41.637	5.721	7.28

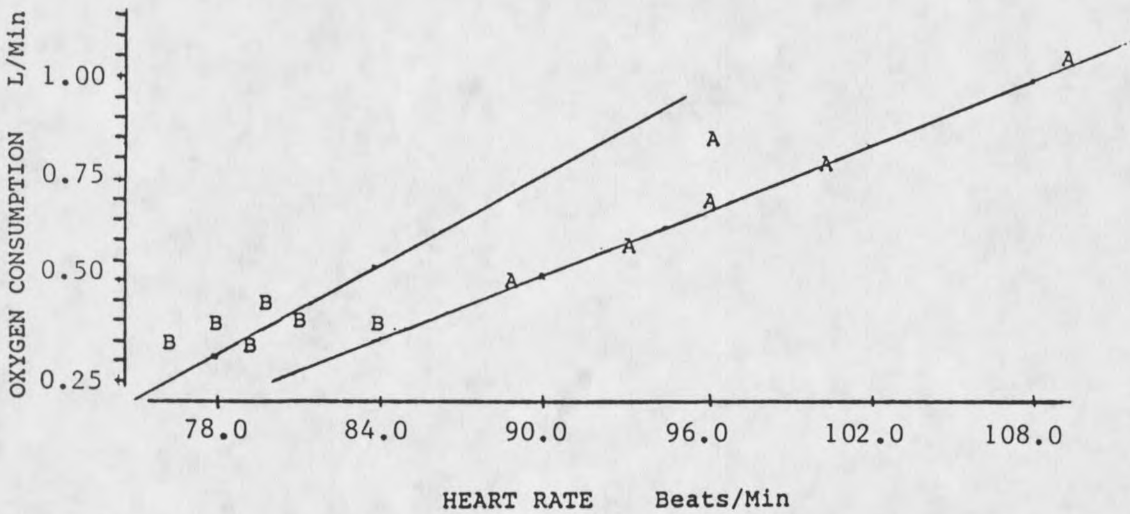
S = 2.821 R^2 = 93.0%

Regression Equation: B
WATHR1 = 72.3 + 17.1 WAT$\dot{V}O_2$1

Predictor	Coef	SD	t-ratio
Constant	72.281	2.042	35.40
WAT$\dot{V}O_2$1	17.143	4.827	3.55

S = 1.568 R^2 = 75.9%

Figure 2
Relationship for $\dot{V}O_2$ and HR in Land and Aqueous Environment
Subject I, Trial II



A=LAND$\dot{V}O_2$1 vs. LANDHR1 B=WAT$\dot{V}O_2$1 vs. WATHR1

Regression Equation: A
LANDHR2 = 72.9 + 32.5 LAND$\dot{V}O_2$

Predictor	Coef	SD	t-ratio
Constant	72.890	4.529	16.09
LAND$\dot{V}O_2$	32.513	5.895	5.52

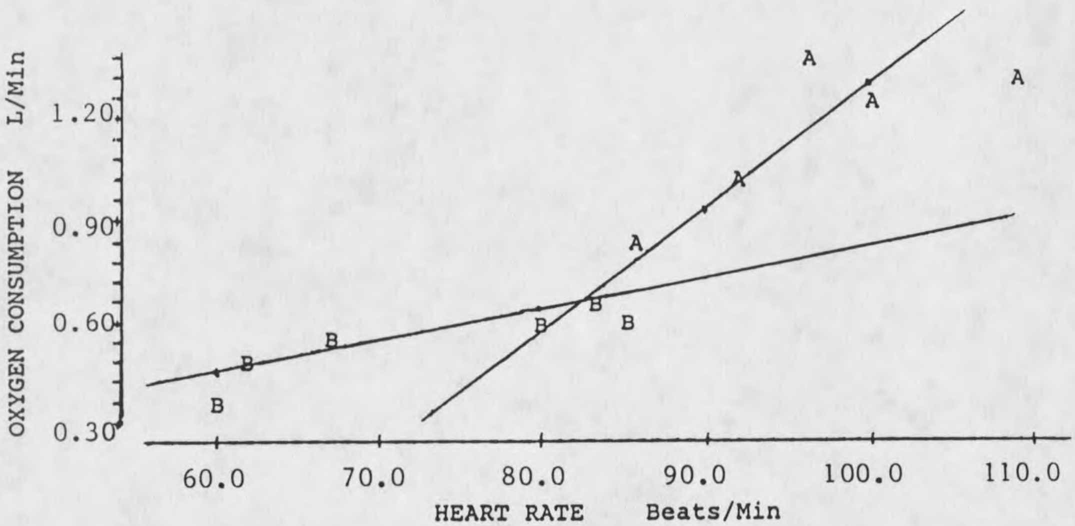
S = 2.612 R^2 = 88.4%

Regression Equation: B
WATHR1 = 68.3 + 28.8 WAT$\dot{V}O_2$2

Predictor	Coef	SD	t-ratio
Constant	68.34	14.31	4.78
WAT$\dot{V}O_2$1	28.80	36.25	0.79

S = 2.839 R^2 = 13.6%

Figure 3
Relationship for $\dot{V}O_2$ and HR in Land
and Aqueous Environment
Subject II, Trial I



A=LAND$\dot{V}O_2$1 vs. LANDHR1 B=WAT$\dot{V}O_2$1 vs. WATHR1

Regression Equation: A
LANDHR1 = 61.1 + 30.9 LAND$\dot{V}O_2$1

Predictor	Coef	SD	t-ratio
Constant	61.10	15.51	3.94
LAND$\dot{V}O_2$1	30.87	13.29	2.32

S = 5.968 R^2 = 64.3%

Regression Equation: B
WATHR1 = 22.7 + 90.8 WAT$\dot{V}O_2$1

Predictor	Coef	SD	t-ratio
Constant	22.72	12.90	1.76
WAT$\dot{V}O_2$1	90.84	23.00	3.95

S = 5.620 R^2 = 79.6%